Inverse Design Problems in Electromagnetics and Nano-Photonics

Eli Yablonovitch
UCLA Electrical Engineering Dept., Los Angeles CA 90095-1594

Chiu-Yen Kao, and S. Osher
UCLA Mathematics Dept., Los Angeles CA 90095

Maxwell's equations are to photonic crystals, as Schrodinger's equation is to conventional crystals. Since photonic crystals are purely products of our imagination, the question has always been what is the exact structure that should be fabricated? This is particularly true for 2-dimensional thin photonic crystals, which can be mass-produced in any Silicon foundry. Nevertheless, it is not yet clear what is the exact 2-d structure that would achieve a desired goal.

Engineering design is formally a type of mathematical Inverse Problem. The design goal is a certain electromagnetic specification or desired electromagnetic performance. It is necessary to work backward from that goal to the exact design of the dielectric boundary that achieves that objective. For example, in mathematics, the Level Set Method has emerged[1] as an excellent tool that can contribute to algorithms[2] for the optimization of boundaries and edges.

In the Photonic Crystal field, the era of purely intuitive design may now be obsolete. We must now concentrate more on design software, rational design, and the numerical solution of inverse problems. There are a number of inverse algorithms, including genetic algorithms, the error-propagation method, and simulated annealing, that can contribute to future progress in photonic crystal design. It is expected that the study of photonic crystals will more and more become the study and development of rational inverse design algorithms and software.

Periodic structures sometimes emerge as optimal solutions to a design problem, but not every design problem has a photonic crystal solution. We have queried the software for the ideal 2-d photonic crystal structures to create high lying bandgaps, even up to the 11$\Rightarrow$12 bandgap. The 2-d photonic crystal geometry that emerges from the software is rather exotic, and would have been difficult to find such structures by human trial and error.

We believe that such software will be essential for designing and optimizing the 2-d Silicon nano-photonic circuits that are now becoming available.

[1] Osher, S.J.; Santosa, F. **Level set methods for optimization problems involving geometry and constraints,** Journal of Computational Physics, vol.171, (no.1), Academic Press, 20 July 2001.
Chiu-Yen Kao, S. Osher, and E. Yablonovitch, "**Maximizing Band Gaps in Two-Dimensional Photonic Crystals, using Level Set Methods**", submitted for publication.
[2] S.J. Cox, J. Funct. Anal, 133:30-40,1995
S.J. Cox and D.C. Dobson, SIAM J. Appl. Math, 59:2108-2120, 1999
S.J. Cox and D.C. Dobson, J. Comput. Phys., 158:214-224, 2000
J.M. Geremia, J. Williams, and H. Mabuchi, Phys. Rev. E., 66, 06606, 2002
Yu Chen, Rong Yu, Weifei Li, Nohadani O, Haas S, Levi AFJ. **Adaptive Design Of Nanoscale Dielectric Structures For Photonics**. Journal of Applied Physics, vol.94, no.9, 1 Nov. 2003, pp.6065-8